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VARIATIONS OF LATITUDE.

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THERE was published in the *Astronomical Journal* of November, 1891, an article on "The Variation of Latitude." Its author was Mr. S. C. Chandler, an American amateur in astronomy. The article attracted the attention of the astronomical world, and at once was subjected to fierce criticism from almost every quarter. To-day, however, the question is no longer an open one, for those who assailed it have, one by one, accepted it as established beyond a doubt.

In order to make clear what is to be said on the variation of latitude, it is necessary to go back about 200 years, to ascertain what was known and what was done along the line indicated by the title of this paper. In 1693 there was born, in Sherbourn, England, a child, James Bradley by name, who was to become one of the greatest of astronomers. He was one of those who are not content simply to amuse themselves with a telescope, but rather had the ambition to do earnest work, and the spirit to choose a problem which his predecessors for more than a century had failed to solve.

The Copernican theory that the sun is the center of the solar system and that the earth moves round the sun established a corresponding apparent change in the places of the stars. The absence of any appreciable change in the position of the fixed stars, when observed at opposite extremities of the earth's orbit, was one of the earliest objections, as well as the most serious one, that had been urged against the earth's motion; and it was always considered that the detection of such a change by observation would furnish absolute proof that the earth is not the center of the solar system. In the attempt to detect the annual parallax of the fixed stars, Bradley made his famous discovery of the aberration of light. Its discovery is universally regarded as one of the most important advances ever made in the field of astronomical science. The sagacity of Bradley in the establishment of this law, as well as in the detection of its physical cause, entitles him to a place among the greatest philosophers of ancient or modern times.

While at work investigating the phenomenon of aberration, Bradley found that some stars near the equinoctial colure had a greater change of declination than a mean annual precession of fifty minutes would give. But on observing stars near the solstitial colure, the change of declination was found to be less than the quantity due to the same value of precession. During an interval of five years, he found some of the stars near the solstitial colure had changed their declination nine or ten minutes less than the amount due to a precession of fifty minutes, while others near the equinoctial colure had an equal change of declination in the opposite direction. Bradley was led to ascribe the phenomenon to an oscillation of the earth's axis, brought about by the disturbing action of the moon upon the earth's equator. He saw that the apparent movements of all stars were in this case the same, and he knew that a movement of this kind can be referred not to the stars themselves, but to the plumb-line from which their directions are measured. He had thought out the possible causes of such a movement of the plumb-line or of the earth itself, and that there might be a nutation which would go through a cycle of about nineteen years, the period of revolution of the moon's nodes.

At the end of nineteen years of observation Bradley found his conclusions verified, and his second great discovery, that of nutation, was established. Had he lived longer, a third great discovery might have crowned his efforts. He had presented to the astronomical world the discovery of the aberration of light; he had discovered the nutation of the earth's axis; he had found the physical causes of these two phenomena; and with a little more opportunity he might have added another great discovery, namely, the variation of latitude. The axis of the earth may move in one or two ways: either it may point to a different star, remaining fixed relatively to the earth, as in the case of nutation, or it may actually change its position in the earth. This second movement was not discovered until a century and a half had elapsed after the death of Bradley. But he was on the track that would have led him to its discovery. When he had fully established the principle of the nutation of the earth's axis, he found that there was concealed somewhere in his new-found theory another principle or residuum.

Now, as to the change of position of the earth's axis in the very body of the earth itself. There is a certain star in the northern heavens called the pole star, and at any particular place in the northern hemisphere of the earth this star is constantly seen at a definite height above the horizon, which is the latitude of the place. With a telescope, the pole star is found to be not absolutely stationary, but describes a small circle in the heavens every twentyfour hours. The axis of the earth about which it rotates points to the center of that little circle, and any change can therefore be determined by observing the motions of the pole star. It is found, too, that the size of the circle increases or diminishes, thus indicating that the earth's axis is pointing farther away from the pole star, or nearer to it. This movement is due to precession, as has been known ever since the days of Hipparchus. The circle described by the present pole star is now getting smaller, but in the course of years .it will increase in size, until after thousands of years it will cease to be the north star. Other stars, one succeeding the other, each at about twenty-three and one-half degrees from the pole, will become in turn the pole star.

Again, the center of the circle may change its position, and no longer be at the same height above the horizon of any given place. If this is true, then the earth's axis must be shifting in the earth itself; in other words, the north pole is not remaining in the same place. If the change in position should ever become a large one terrestrial climates would be subject to very great changes; but the truth is that the changes are small and the effect on climate is scarcely appreciable. Fifteen or twenty years ago no one believed that the north pole of the earth moved. Even the finest astronomical observations of that time failed to detect any such movement. Yet we have reached a point where the facts clearly show that the north pole does move—not very much, but still to an extent that is easily measured by astronomical observations.

Mr. Chandler found that there is a revolution of the earth's pole in 427 days, from west to east, with a radius of thirty feet, measured at the earth's surface. He assumed, for the purpose of statement, that this is "a motion of the north pole of the principal axis of inertia about that of the axis of rotation; the direction of the former from the latter lay towards the meridian of Greenwich about the beginning of the year 1890. This, with the period of 427 days, will serve to fix approximately the relative positions of these axes at any other time for any given meridian." This was in flat contradiction to all accepted views. The only period in which the earth's pole could revolve was believed at that time to be ten months. The radius of its path had been declared to be insensible, and now comes Mr. Chandler affirming that the period was a variable one, and that the path had a radius of thirty feet.

In confirmation of his theory, an examination of the observations of a German astronomer, of Berlin, furnished Mr. Chandler another fact, namely, when the Cambridge, United States, latitudes were the smallest, those of Berlin were the largest; that is to say, if the north pole moved nearer America, it must move further from Europe; and, on the other hand, if further from America, then nearer Europe. There was something perplexing about these movements, as they had been known for a long time, but no satisfactory solution had been given. Mr. Chandler solved the problem, and the difficulties were removed.

To show that there is a deviation of the earth's pole from its average position, two tables, prepared by Chandler, showing the distances of the earth's pole, in feet, from its average position, are herewith given, each representing a year's observations. The signs plus and minus indicate opposite directions of displacement. The first table was made at Washington, D. C., and the other at Pulkowa, near St. Petersburg.

Washington.		*Pulkowa.*	
December, 1864	−28 feet.	July, 1865	−18 feet.
March, 1865	− 1 "	September, 1865	+ 3 "
June, 1865	+15 "	November, 1865	+26 "
August, 1865	+22 "	February, 1866	+18 "
October, 1865	+11 "	June, 1866	−11 "
December, 1865	−17 "	July, 1866	−16 "

The figures are not exact in every case, but the error in them is always a very small one. Every expert astronomical observer knows how difficult a matter it is to obtain the position of the earth's pole to within a foot.

Mr. Chandler's investigation of the results reached by other astronomers, and comparing them with his own, arrived at the conclusion that there was, besides the vibration of the earth's axis in the body of the earth, also an increase in the period of polar revolution. At the time of Bradley's observations the period was shorter by about two months than it is now. Whether this movement is subject to a periodicity, reaching at one time a maximum and then a minimum, is not yet determined. But it is certainly known that at times there are very irregular movements, due to some cause or other, followed by others that are subject to a periodicity.

Chandler says: "Another characteristic which has struck my attention, although somewhat vaguely, is that the variations in the length of the period seem to go hand in hand with simultaneous alterations in the amplitude of the rotation; the shorter periods being apparently associated with the larger coefficients for the latter."

Almost all of the series of observations of any extent which have been examined are peculiar in that they manifest the periodicity quite uniformly and distinctly for a number of years, then for a while irregularly and obscurely.

Simon Newcomb, one of the greatest of living astronomers, in his discussion of Chandler's theory, writes as follows:

"Mr. Chandler's remarkable discovery, that the apparent variations in terrestrial latitudes may be accounted for by supposing a revolution of the axis of rotation of the earth around that of figure, in a period of 427 days, is in such disaccord with the received theory of the earth's rotation that at first I was disposed to doubt its possibility. But I am now able to point out a *vera causa* which affords a complete explanation of this period. Up to the present time the treatment of this subject has been this: The ratio of the moment of inertia of the earth around its principal axis to the mean of the other two principal moments admits of very accurate determination from the amount of precision and nutation. This ratio involves what we might call, in a general way, the solid ellipticity of the earth, or the ellipticity of a homogeneous spheroid having the same moments of inertia as the earth.

"The question now arises whether Mr. Chandler's result can be reconciled with dynamic theory. I answer that it can, because the theory which assigns 306 days as the time of revolution is based on the hypothesis that the earth is an absolutely rigid body. But, as a matter of fact, the fluidity of the ocean plays an important part in the phenomenon, as does also the elasticity of the earth. The combined effect of this fluidity and elasticity is that if the axis of rotation is displaced by a certain amount, the axis of figure will, by changed action of the centrifugal force, be moved toward coincidence with the new axis of rotation. The result is, that the motion of the latter will be diminished in a corresponding ratio, and thus the time of revolution will be lengthened. I think the result of investigation will be that the rigidity derived from Mr. Chandler's period is as great as that claimed by Lord Kelvin from the phenomena of the tides."

Mr. Chandler himself says: "It is unnecessary for the purpose of disposing of objections to insist that it is not sufficient to show that the observed variations, attributed to the unsteadiness of the earth's pole, are near the limit of precision attainable in linear differential measures, and in the indication of the direction of gravity by means of the air-bubble of the level; or to show that there are known variations in divided circles and in levels, dependent on temperature and seasons. Nor need we even urge the fact that a large portion of the data which have been utilized in the present researches on the latitude were derived by methods which dispense with levels, or with circles, a part of them indeed with both, and yet that the results of all are harmonious. On the contrary, let us admit, although merely for argument's sake, that all the known means of determining the direction of gravity are subject to a common law of periodical error which vitiates the result of astronomical observation, obtained by whatever methods, and in precisely the same manner. Now, the observed law of latitude variation includes two terms, one a period of fourteen months, and the other of twelve. Since the phases of the first term are repeated at intervals of two months in successive years, and hence in a series of years come into all possible relations to conditions of temperature dependent on season, the argument against the reality of the fourteen months' term absolutely fails."

Heretofore the observations made by astronomers in Europe and America, in all of which there was some puzzling error, were immediately rectified when Mr. Chandler applied his new rule to them. The constant of aberration has been wonderfully improved, but there is room yet to secure greater accuracy.

Again, if the axis of the earth is making small oscillations of this kind, there should be an effect upon the tides. The ocean should feel the swinging motion of the earth's axis in some way. The tidal registers show that there is a distinct effect. The rise and fall of the tide are only a few inches, but they are evidences of an irresistible character that the earth is turning around in an unbalanced vibration. The vibration at one time is waxing and at another waning.

In conclusion, it may be said that in the consideration of this subject we find that when Bradley, 160 years ago, began to work out the problem of parallax, he was led to the discovery of the "aberration of light," and finding that an uncertain element persisted in presenting itself at every turn of his work, he was led to the discovery of the nutation of the earth's axis. But even at this point he found another difficulty remaining over. Death cut short the work of the great astronomer. Twenty years ago the work was resumed by an American. Now it is an accepted fact that not only does the earth's axis spin around, according to the theory of nutation, but there is another and stronger motion of the earth's axis, and that is, that there is an actual change of the position of the earth's axis in the earth itself, causing the latitude of the earth to change at every point on its surface.